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OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

DEPARTMENT OF GEOPHYSICAL SCIENCES
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

MEASUREMENTS OF THE GLOBAL DISTRIBUTION OF CARBON MONOXIDE IN THE TROPOSPHERE

By

Rebecca R. Hinton

Principal Investigator: Earl C. Kindle

Progress Report
For the period January 1, 1981 to December 31, 1981

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Cooperative Agreement NCCI-2
Henry G. Reichle Jr., Technical Monitor
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Submitted by the
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P.O. Box 6369
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By

Earl C. Kindle[1] and Rebecca R. Hinton[2]

The following annual report describes research performed under agreement NCCI-2 between Old Dominion University Research Foundation and NASA/ Langley Research Center during the period January 1 to December 31, 1981. The report contains four sections:

1. a brief summary of tasks completed during 1981;

2. a projection of selected activities to be undertaken in 1982;

3. a final report, "Global Tropospheric Experiment - Test Flights 1981: Carbon Monoxide and Methane Results, (Appendix A)" and

4. an interim report, "MAPS/OSTA-1 East Coast Correlative Measurements Carbon Monoxide Results, (Appendix B)."

TASK COMPLETED DURING 1981

Three phases of work were successfully completed during 1981. Phase one included equipment assembly, start up, familiarization, and testing. Phase two involved participation in a series of flights for the Global Tropospheric Experiment. The third phase directly supported the MAPS/OSTA-1 mission.

Phase One

The first task was to bring the modified Varian model 2740 gas chromatograph to operational status because the instrument had not been reassembled following its return to NASA/LaRC. By mid-April, the instrument had been successfully rewired, replumbed and initial familiarization completed. Between April and December nearly 1500 samples and standard gas mixtures

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were analyzed. Approximately 20% of a person-year was required for the analysis of that number of samples.

A need for more grab sample bottles to be used in support of the MAPS/OSTA-1 correlative measurements program was identified. The 300 ml stainless steel cylinders and fittings were acquired, heat treated in air at 1000°C to remove contaminants, and assembled into two racks of ten bottles each. The newer bottles had oxidized surfaces, but the older original bottles that had been heat treated in vacuum had shiny, unoxidized surfaces.

A test to determine the possible impact of different surface chemistry on sample carbon monoxide concentration was begun. Unfortunately, the 56-Hour Shuttle Simulation required use of the bottles before the test could be completed. Data for 72 hours showed no significant change (< 2% at 1.25 ppm) in carbon monoxide levels in either oxidized or unoxidized sample bottles. However, the test should be repeated for a longer period of time with more replicates for greater statistical accuracy. Prior to flight all eighty sample bottles were leak tested to prevent sample contamination or loss.

All gas chromatographic analyses are based on calibration with "standards." Thus, it is ultimately important that the concentration of the chemical species of interest in the standard be known with certainty. While the primary carbon monoxide/methane gas standard had a calibration confirmed by several respected laboratories several years ago, a more recent confirmation of nominal cylinder concentrations was needed. Three cylinders of gas standards were analyzed by the National Bureau of Standards. Nominal methane concentrations on all three fell within one standard deviation of the NSB analysis indicating very close agreement. Carbon monoxide was also analyzed, but difficulties due to column configuration prevented the NBS from certifying the result even though the nominal concentrations for two cylinders fell within 1 to 5 percent of the analytical values.

Continuous long-term data sets such as those obtained in support of the MAPS program over the past eight years are rare. Therefore, any consideration of changes in the chromatographic technique must be carefully considered. The only modification made this year to the instrument was a shortening of the column containing the hot nickle catalyst from 15.0 cm to 12.5 cm.

Shortening the tube, but still using the customary one g of catalyst reduced the dead volume. This small reduction in dead volume at such a critical location improved the precision of the analysis (from 2 - 3% to 1% with standard gases).

The present cryogenic preconcentration system requires the entire contents of a 300 ml sample bottle pressurized to about 28 psi to flush and fill the 100 ml sample loop. If for any reason replicates from the same bottle are required, the use of the 20 ml sample loop with a change in the 1/8 in. dia. tubing going from the methanized to the detector to 1/16 in. dia. tubing works well. These two changes provided half as many counts (~ 200,000/1 ppm CO) as with the 100 ml sample, but use only half as much of a valuable sample. This is not the usual mode of operation.

Analytical support was provided on two occasions to the Atmospheric Chemistry Branch/MATD. Concentrations of methane in experimental gas samples were confirmed for R.W. Cofer III. Experimental and carrier gases used in a microwave/mass spectrometer apparatus were analyzed for J. Pellet. The lack of carbon monoxide in the gases revealed by our analysis allowed the investigator to look for other sources of contamination in the mass spec system.

Phase Two

Preparation for a test flight for the Global Tropospheric Experiment (GTE) began in late May. The purpose of the 1981 GTE instrument test flights was to demonstrate the ability of a large-scale airborne sampling program to provide simultaneous measurements of selected tropospheric pollutants. Because of the limited lead time and space constraints, the grab sample system rather than the entire chromatographic system was prepared for mounting in the NASA Electra aircraft. The grab sampling procedure, analytical method, and carbon monoxide and methane results of the four flights are reviewed in a final report attached to this document. A technical paper examining the relationship among simultaneously sampled carbon monoxide, methane, ozone, and aerosol concentration has been accepted for publication in a conference proceedings. Participation in the GTE flight program during 1982 is anticipated.

Phase Three

Analytical support was provided for the MAPS/OSTA-1 Correlative Measurements Program. The Correlative Measurements Program provided ground truth data on tropospheric carbon monoxide concentrations underneath the orbital path of the second Space Shuttle, Columbia, which carried aloft a gas filter correlation radiometer in mid-November 1981. In addition to the actual mission during which two flights were completed, data was collected from two flights during the 56-Hour Shuttle Simulation in early September. A pre-mission shake-down flight was also performed with the Lear Jet, but only five samples were analyzed.

The assistance of Ms. Vickie Connors, Old Dominion University graduate student, is gratefully acknowledged. Ms. Connors participated in every phase of the mission including assembly of grab sample bottles and racks, maintaining and calibrating the chromatograph, and handling samples.

A preliminary report of the carbon monoxide measurements and physical data for both the 56-Hour Shuttle Simulation and the actual MAPS/OSTA-1 Correlative Measurements mission is attached to this report. Participation in interpretation of the data will continue.

PLANNED ACTIVITIES FOR 1982

During 1982, grants participants will continue to support the reduction and reporting of MAPS/OSTA-1 carbon monoxide data. Assistance in evaluation of correlative measurements techniques will be provided. A variety of related activities are also planned.

Two papers dealing with carbon monoxide and methane research performed by participants in this grant have been accepted for publication/presentation at a conference on the Non-urban Troposphere to be held in Williamsburg, VA in spring 1982. The first paper examines seven years of historical data on methane concentrations along the southeast Atlantic Coast. A great deal of speculation and controversy surrounds the modeling of free tropospheric methane. Increases in atmospheric CH_4 may be due to its chemical competition with (chiefly) carbon monoxide and nonmethane hydrocarbons (NMHC) for oxidation. Simultaneous measurements of multiple carbon species,

and with gas chromatography, over long time periods provide necessary data for resolution of this controversy. The second paper presents data obtained on the Global Tropospheric Experiment Test Flights 1981. Simultaneously acquired carbon monoxide, methane, ozone, aerosol and physical data are examined for trends and correlations.

Participating in the Global Tropospheric Experiment will continue. A summer flight similar to last year's is planned. Although plans are still incomplete, the entire chromatographic system will be readied for flight as well as the grab sample system used previously. A random discrepancy in results of carbon monoxide measurements between DACOM and the gas chromatograph was observed during the test flight. An investigation of the nature and cause of the discrepancy has been planned prior to the summer flight and awaits funding. Briefly; a series of National Bureau of Standards calibration gases will be used to determine DACOM's sensitivity to low (i.e., 50 to 200 parts per billion) carbon monoxide values.

In addition, the possibility exists that a newer, smaller gas chromatograph currently on loan to NRL will be returned to NASA/LaRC this year. A sensitive instrument may eliminate the need for such a large sample size (i.e., 100 ml). A rigorous series of intercalibration samples is planned to assure continuity of data previously acquired with our currently used "standard gas chromatograph" and analytical technique. A technique for simultaneous carbon monoxide and carbon dioxide analysis has been successfully developed and may be investigated.

APPENDIX A

GLOBAL TROPOSPHERIC EXPERIMENT TEST FLIGHTS 1981: CARBON MONOXIDE AND METHANE REPORT

GLOBAL TROPOSPHERIC EXPERIMENT TEST FLIGHTS 1981: CARBON MONOXIDE AND METHANE REPORT

ABSTRACT

Chemical and physical atmospheric data were collected during the NASA Global Tropospheric Instrument Test Flights in July 1981. Carbon monoxide (CO) and methane (CH_4) grab samples were obtained simultaneously with ozone (O_3), aerosol, nitric oxide (NO) and DACOM CO measurements. Eighty grab samples were collected at various altitudes up to 19,000 ft. along a north-south flight path from Wallops Flight Center, VA to 11° N. CO and CH_4 were analyzed by flame ionization gas chromatography with cryogenic preconcentration. The relationship between CO and O_3 concentrated is examined. A comparative analysis between trends in aerosol and CO concentration is performed.

GLOBAL TROPOSPHERIC EXPERIMENT TEST FLIGHTS 1981: CARBON MONOXIDE AND METHANE REPORT

A series of four instrument test flights were flown for the Global Tropospheric Experiment (GTE) during July 1981. The purpose of the flights was to demonstrate the feasibility and value of simultaneously measuring several specific atmospheric pollutants. Carbon monoxide (CO) and methane (CH_4) grab samples were obtained simultaneously with ozone (O_3), aerosol, nitric oxide (NO) and DACOM CO measurements.

The location of the four flights of the 1981 program are shown in Figure 1. The sampling platform platform was a Lockheed Electra, a four engine turboparop aircraft.

The first test flight, July 9, 1981 was a 3 hours and 20 minutes east/west excursion over open ocean originating and terminating at Wallops Flight Center, VA (WFC). The second flight, July 14, 1981, originated at WFC with a $5^{1/2}$ hour south-easterly flight to San Juan, P.R. On July 15, 1981, the third flight of 3 hours and 45 minutes went as far south as 11°30' and returned to San Juan. The fourth flight, July 16, 1981, was a $5^{1/2}$ hour return flight from San Juan to WFC. Altitudes varied in random steps from 5 to 0.5 km on each flight. During the flights, more than 80 grab samples were collected and later analyzed for CO and CH_4 using the following procedure.

Sample Collection and Analysis Procedure

Tropospheric grab samples were collected in 300 ml-stainless steel sample bottles. Bottles were preconditioned by heating in air or vacuum to 1000°C to remove contaminants (e.g., tooling lubricants, fingerprints, solvents). Following preconditioning, bottles were assembled in racks of ten (wt. 11.4 Kg) to facilitate handling and securing of sample contaimers in an aircraft. Bottle racks were secured by locking pins to the forward section of a pallet installed in an aircraft equipment rack. The rear section of the pallet held two 1/8 HP neoprene diaphragm pumps connected in series by 0.6 cm-dia stainless steel tubing. The "L" shaped pump sample inlet port extended 18 cm outside the fuselage just aft the co-pilot's station. The pitot-like inlet port was valved to prevent entraining debris into the pumps on takeoff and landing.

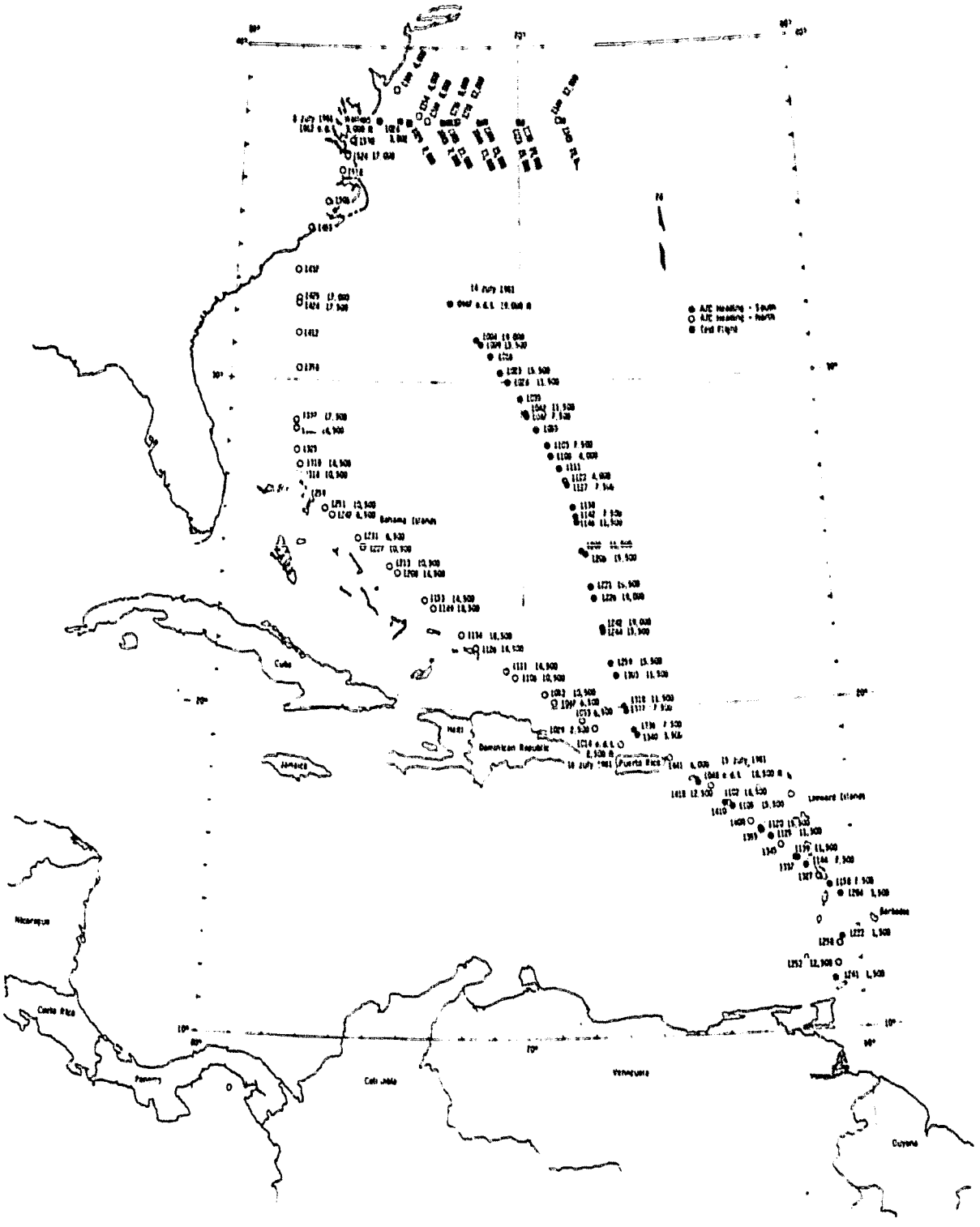

Figure 1. Location of the 1981 NASA Global Tropospheric experiments test flights.

Prior to each sample collection, the pumps were operated for at least one minute to purge the system with ambient air. Each evacuated sample bottle was filled and flushed twice during sampling before the final filling to a pressure of 28 to 30 psig.

Samples were returned to the laboratory and analyzed by flame ionization (FID) gas chromatography. A modified analytical technique (Condon, 1977) similar to that of Swinnerton, et al. (1962, 1962a, 1967, 1968) was used to measure CH_4 and CO in trace amounts (Figure 2). The pressurized sample bottle is connected to a gas transfer manifold. The grab sample flushes and fills a 100 ml sample loop. The sample is carried from the sample loop by transfer helium (He) through two cold traps immersed in liquid nitrogen. The first trap of activated alumina with 10 percent by weight paraffin oil removes CO_2 and hydrocarbons heavier than methane. A drying tube of magnesium perchlorate removes water. The second cold trap of 25 percent by weight activated charcoal and 75 percent molecular sieve 5A 60/80 mesh collects CO and CH_4 from the sample. The traps are isolated by valves from the transfer He, allowed to warm at room temperature for two minutes, and then heated to 100°C with boiling water to desorb the CO and CH_4. The carrier He (flow rate 60 ml/min) moves the sample through a 2 m length of 0.6 cm-dia column packed with molecular sieve 5A and held at ~100°C. Because CO is not directly detectable using FID, the CO is catalytically reduced over hot (325°C) nickel catalyst and detected as the second CH_4 peak to elute. The sample CH_4 is detected about one min. earlier (Figure 3). Peak areas are reported as counts by a digital integrator and plotted on a strip chart. Sample concentrations are read from a calibration plot that is made by plotting the peak areas of calibration gas standards with known concentrations of CO and CH_4. An internal standard, a calibration gas with an appropriate concentration of CO and CH_4, is analyzed every fourth or fifth sample to correct for instrument drift.

Samples taken on July 9 were analyzed within two days. All other samples were analyzed at least four days after collection. Aging may adversely affect CO measurements due to chemical reactivity of the species, but does not interfere with CH_4 analysis. Thus, installation of a gas chromatograph on the aircraft to provide direct analysis is preferred for extended missions.

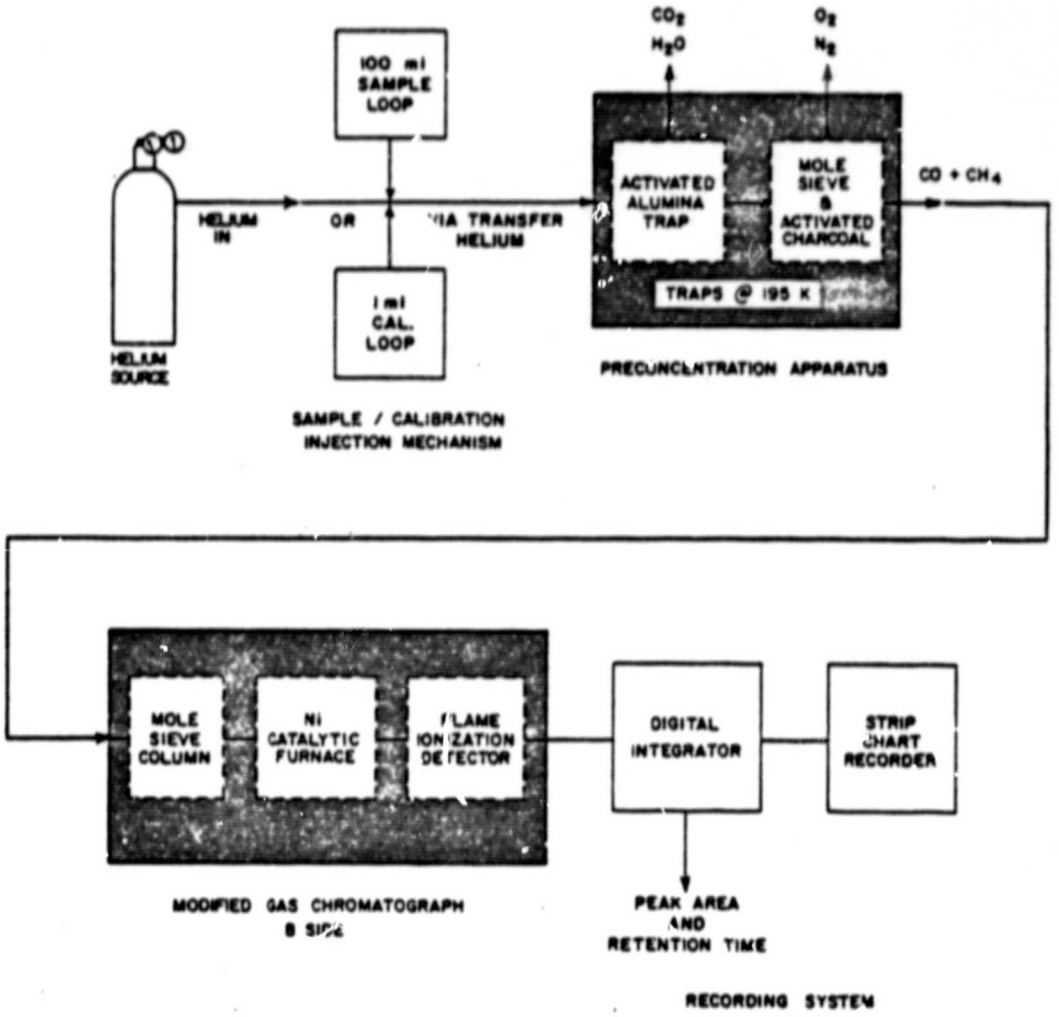

Figure 2. Block diagram of the modified gas chromatograph used to analyze CO/CH_4.

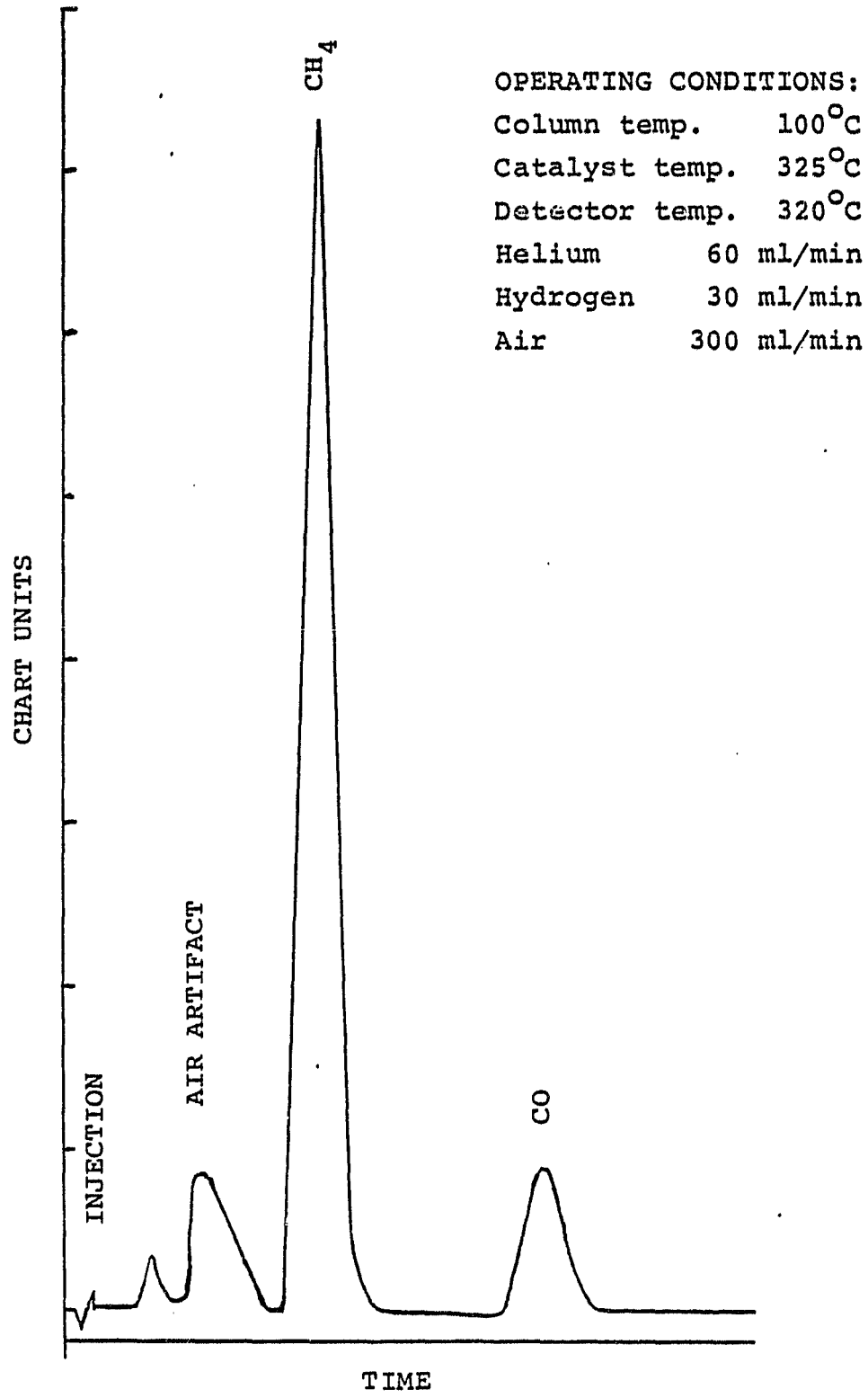

Figure 3. A typical chromatogram from July 9, 1981. Grab sample 88 was taken within a haze layer near the coast (38°50'N/74°55'W) at 0.61 km. CH_4 = 1.68 ppmv CO = 390 ppmv.

RESULTS

Physical and chemical data are reported for each of the four flights in Tables 1-4. Methane concentrations generally decreased slightly with increasing altitude. Methane concentrations also varied slightly as a function of latitude. The CH_4 means and standard deviations were as follows:

1.60 ± 0.04 ppmv	July 9, 1981	test flight
1.67 ± 0.03 ppmv	July 14, 1981	to San Juan
1.61 ± 0.02 ppmv	July 15, 1981	Caribbean flight
1.68 ± 0.02 ppmv	July 16, 1981	from San Juan

The analytical precision based on analysis of calibration gases was ±2% and the variation among replicate samples taken during the flight was ±4%.

Carbon monoxide values observed were slightly higher than the expected Northern Hemisphere average of 150 ppbv (Seiler and Fishman, 1981). CO means and standard deviations were observed as follows:

280 ± 81 ppbv	July 9, 1981	test flight
128 ± 80 ppbv	July 14, 1981	to San Juan
183 ± 38 ppbv	July 15, 1981	Caribbean flight
189 ± 58 ppbv	July 16, 1981	from San Juan

Some analytical difficulties were encountered in the analysis of CO. Samples taken on July 9 were analyzed within two days. All other samples were analyzed at least four days after collection. Aging may adversely affect CO measurements due to chemical reactivity of the species (i.e., with sample bottle walls, other gases in the sample, etc.), but does not interfere with CH_4 analysis. Thus, installation of a gas chromatograph on the aircraft to provide direct analysis is preferred for extended missions. Another difficulty encountered in analysis was the post facto discovery of CO contamination in the He carrier gas. This contamination caused a reevaluation of the CO values initially obtained for July 14-16, 1981. The data in this report have been corrected by the application of a blanket correction factor (on the order of 100 ppbv). In the future, greater care will be exercised in checking all operational gases for contamination.

Table 1. Global tropospheric experiment CO and CH_4 data Wallops test flight July 9, 1981.

Altitude (ft)	Altitude (Km)	Time (EDT)	Lat/Lng (°N)(°W)	Temp (°C)	D. P. (°C)	CH_4 (ppm)	CO (ppbv)
1000	0.30	9:57	38°00/75°13	29.1	20.1	1.62	466
2800	0.85	10:01	37°57/75°16	28.6	18.4	1.63	441
2910	0.87	10:09	37°48/75°16	28.5	17.6	1.63	377
2920	0.89	10:10	37°49/75°11	28.5	17.8	1.61	379
4000	1.22	10:25	37°51/74°01	28.2	11.7	1.62	325
6000	1.83	10:26	37°52/74°06	21.2	9.4	1.61	320
6860	2.09	10:29	37°50/73°49	20.5	7.4	1.59	290
8000	2.44	10:44	37°52/72°37	23.4	-16.4	1.54	215
10000	3.05	10:46	37°54/72°43	19.4	-10.7	1.58	230
10880	3.32	10:48	37°50/72°32	20.0	-10.4	1.58	227
13180	4.02	11:05	37°56/71°16	13.0	-19.1	1.57	261
14750	4.50	11:09	37°52/71°11	11.3	-21.1	1.58	242
17000	5.18	11:25	37°56/69°44	5.5	-23.4	1.57	224
18750	5.71	11:29	37°45/69°39	3.3	-25.4	1.56	189
17000	5.18	11:44	37°45/68°12	7.4	-27.7	1.58	204
15000	4.57	11:46	37°51/68°18	11.8	-13.7	1.58	219
11880	3.62	11:49	37°51/68°29	17.7	-25.6	1.59	212
11890	3.62	12:03	37°48/69°48	17.5	-11.3	1.60	232
11900	3.63	12:29	37°50/72°05	18.8	-12.9	1.57	239
10000	3.04	12:32	37°44/72°16	23.4	-17.0	1.58	215
7920	2.41	12:35	37°48/72°12	23.9	-16.0	1.56	196
7000	2.13	12:49	37°53/73°22	21.7	10.5	1.58	244
4010	1.22	12:53	38°04/73°33	28.2	12.1	1.64	283
4010	1.22	13:02	38°28/74°03	28.4	14.5	1.68	372
2000	0.61	13:17	38°50/74°55	33.4	20.1	1.68	390

Table 2. Global tropospheric experiment CO and CH_4 data flight to San Juan, P.R., July 14, 1981.

Altitude (ft)	Altitude (Km)	Time (EDT)	Lat/Lng (°N)(°W)	Temp (°C)	D.P. (°C)	CH_4 (ppmv)	CO (ppbv)	Winds (° at kts)
surface	0.01	8:00	37°56/75°28	~25	ND	1.84	374	ND
3000	0.91	8:24	37°08/75°59	23.0	14.4	1.69	275	ND
19000	5.79	8:57	35°48/75°35	3.8	-18.6	1.63	71	ND
18650	5.68	9:47	32°26/72°26	3.4	-16.7	1.66	102	300 @ 14
15230	4.64	10:09	31°14/71°21	9.4	-12.8	1.59	99	250 @ 15
11190	3.41	10:28	29°54/70°27	13.9	0.1	1.64	168	279 @ 20
11190	3.41	10:41	29°03/69°52	14.1	-6.9	1.66	150	ND
7210	2.19	10:47	29°02/69°49	20.0	7.7	1.66	113	254 @ 11
3820	1.16	11:07	27°44/69°01	24.6	15.8	1.70	52	232 @ 13
7200	2.19	11:26	26°53/68°31	19.3	8.1	1.69	61	243 @ 14
11200	3.41	11:42	25°50/68°18	19.4	7.7	1.66	86	209 @ 13
15200	4.63	12:06	24°45/67°59	8.0	-10.9	1.67	76	178 @ 8
18700	5.69	12:26	23°36/67°48	2.5	-20.3	1.64	79	L.V.
15190	4.63	12:44	22°58/67°30	7.9	-7.5	1.66	72	184 @ 17
11290	3.44	13:03	21°38/67°15	13.6	0.9	1.67	97	263 @ 17
3260	0.99	13:20	20°01/66°53	21.1	18.3	1.70	117	111 @ 20
2500	0.76	13:55	S.J.	27.0	18.5	1.69	116	ND

Table 3. Global tropospheric experiment CO and CH_4 data Caribbean flight to 12°N and return to San Juan, P.R., July 15, 1981

Altitude (ft)	Altitude (Km)	Time (EDT)	Lat/Lng (°N)(°W)	Temp (°C)	D.P. (°C)	CH_4 (ppmv)	CO (ppbv)	Winds (° at kts)
18300	5.58	10:48	17°39/64°38	1.5	-11.4	1.58	131	121 @ 5
15400	4.69	11:06	16°46/63°36	9.1	-22.8	1.60	129	115 @ 16
11460	3.49	11:26	15°51/62°30	15.1	-14.2	ND	ND	117 @ 12
7500	2.29	11:44	14°57/61°29	22.2	-7.3	1.63	173	134 @ 9
3460	1.05	12:04	14°00/60°30	27.6	13.0	1.63	224	79 @ 11
1480	0.45	12:22	12°43/60°33	30.6	23.4	1.62	246	90 @ 20
1500	0.45	12:36	11°29/60°48	30.2	21.8	1.63	244	65 @ 17
12500	3.81	12:51	11°56/60°41	13.5	-10.9	1.61	178	142 @ 25
12500	3.81	13:02	12°53/60°31	11.9	ND	1.60	175	152 @ 25
12400	3.78	13:22	14°11/60°36	13.5	-21.8	1.56	171	116 @ 20
12400	3.78	13:41	15°22/61°51	14.2	-21.6	ND	ND	92 @ 22
12400	3.78	13:59	16°22/63°05	14.7	-21.0	1.60	179	99 @ 19
12000	3.66	14:09	16°58/63°42	15.2	-21.0	1.58	169	117 @ 19
10000	3.05	14:23	17°46/64°30	20.2	-19.3	1.61	180	113 @ 12

Table 4. Global tropospheric experiment CO and CH_4 data flight from San Juan, P.R., July 16, 1981.

Altitude (ft)	Altitude (Km)	Time (EDT)	Lat/Lng (°N)(°W)	Temp (°C)	D.P. (°C)	CH_4 (ppmv)	CO (ppbv)	Winds (° at kts)
2390	0.73	10:08	18°39/66°33	29.0	16.9	1.63	143	100 @ 22
6320	1.93	10:33	19°35/68°13	22.4	8.7	1.66	151	98 @ 17
10400	3.17	10:52	20°22/69°23	17.5	-18.5	1.65	138	84 @ 17
14400	4.39	11:11	21°09/70°36	7.9	-17.7	1.64	148	105 @ 15
18360	5.59	11:35	22°15/72°02	0.9	-17.7	1.68	137	123 @ 10
14290	4.36	11:53	23°17/73°14	9.8	-24.4	1.69	162	L.V.
11440	3.49	12:13	24°21/74°26	16.8	-1.1	1.70	166	90 @ 5
6320	1.93	12:31	25°13/75°31	22.7	9.9	1.69	175	80 @ 18
10320	3.15	12:50	26°31/77°25	16.4	-3.0	1.67	216	330 @ 4
14290	4.36	13:18	27°12/77°35	8.8	-6.8	1.68	175	347 @ 10
17200	5.24	13:38	28°46/77°40	4.7	-19.7	1.67	169	337 @ 9
17200	5.24	14:05	31°01/77°43	5.6	-14.2	1.68	160	300 @ 5
16850	5.14	14:35	33°13/77°49	6.2	9.1	1.67	183	296 @ 19
16850	5.14	14:55	34°38/77°26	6.6	-5.4	1.67	199	315 @ 23
16850	5.14	15:15	36°04/76°35	7.1	-3.8	1.69	280	285 @ 25
14000	4.27	15:33	37°21/75°50	14.0	-3.4	1.71	333	276 @ 17
10000	3.05	15:37	37°39/75°39	14.5	4.0	1.72	287	ND

A flight test was conducted on July 9, 1981, along an ascending stair-step easterly path to a point 550 km offshore with a westernly return along essentially the same route. Data from this flight, as illustrated in Figure 4, demonstrate a direct correlation among vertical aerosol distribution, O_3, and CO concentrations. The results show a decrease in O_3, CO, CH_4, and aerosol concentration with increasing altitude to an altitude of 2.4 km. Satellite imagery, the Lidar aerosol display (shown at the far right of the figure) and observations recorded during the flight indicate that a haze layer extended to an altitude of $\approx$ 2.4 km. Satellite images taken on days prior to 9 July indicate that the aerosol laden air mass encountered over the water resulted from the easterly transport of a continental plume.

High concentrations of CO, CH_4 and aerosol accompany precursors of O_3 production such as nonmethane hydrocarbons (NMHC) and NO_x from natural and anthropogenic sources. This correlation provides a characteristic "thumb print" for that continental air mass. At 2.5 km a "capping" temperature inversion was observed. The region above this inversion is characterized by much drier air with a standard lapse rate, generally uniform concentrations of pollutant species, and significantly decreased aerosol loading.

Results of the Caribbean Flight (Figure 5), a round trip from San Juan, P.R. to Tobago, demonstrate the uniformity and stability of the air mass sampled on July 15 and contrast sharply with results displayed in Figure 4. The temperature profile had a standard lapse rate. A generally inverse correlation was observed between O_3 and CO concentrations which may be characteristic of a more stable air mass. Wind data taken aloft simultaneously with samples indicated an easterly to southeasterly flow throughout the Caribbean region sampled. The scatter in the data for altitudes from 3.5 to 3.8 km is due to a nearly constant altitude flight path that skimmed in and out of the top of the lower stable layer as shown in the lidar display.

Figure 6 presents O_3, CO, and CH_4 concentrations at altitudes flown with respect to latitude. Although interpretation of the latitudinal distribution is clouded by the random variation in altitude, a slight decrease in O_3 and CH_4 concentration was observed in samples taken near the intertropical convergence zone (ITCZ) at about 10°N. CO concentration increases rapidly with decreasing altitude and therefore, mask the ability to determine with certainty the latitudinal distribution. A more detailed

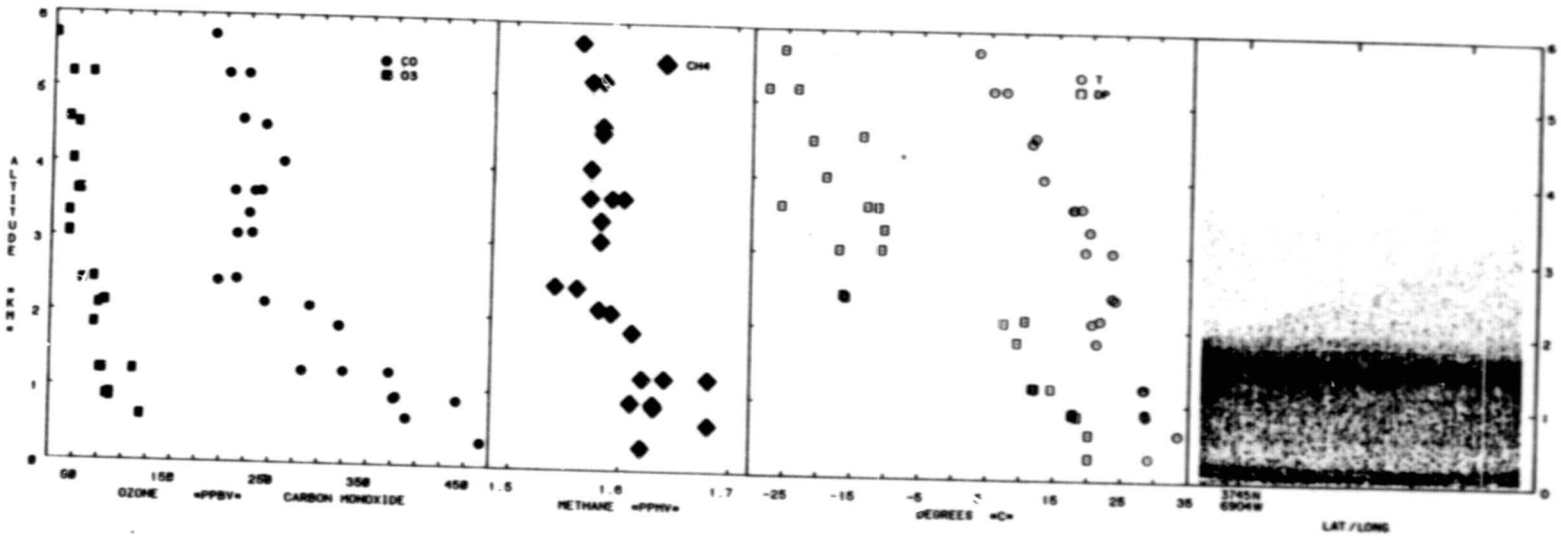

Figure 4. In situ ozone, carbon monoxide, methane, temperature/dew point profile and lidar aerosol results from GTE Wallops test flight, July 9, 1981. Dark areas of lidar display indicate enhanced aerosols. Note inversion at ~2.4 km.

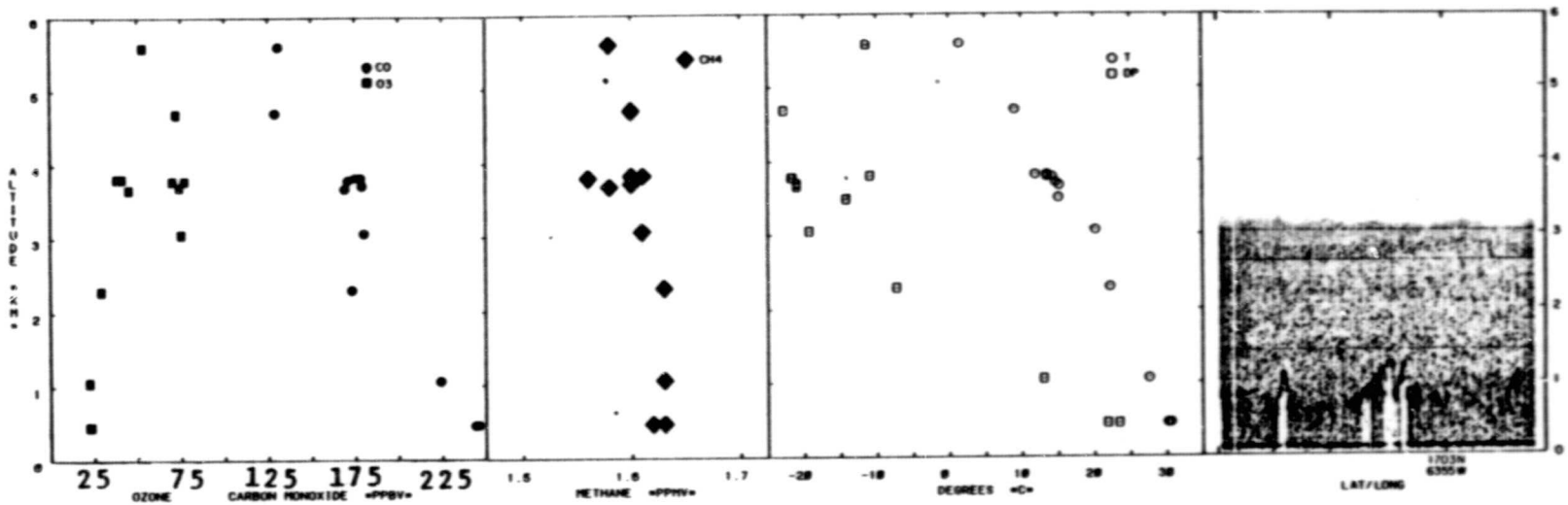

Figure 5. In situ ozone, carbon monoxide, methane, temperature/dew point profile and lidar aerosol results from GTE Caribbean flight, July 15, 1981.

discussion of related aerosol data is presented elsewhere (Browell and Shipley, 1982).

Discussion

Synergistic consideration of simultaneously sampled O_3, CO, CH_4, aerosol distribution, temperature/dew point profiles, winds aloft, and synoptic meterology provides the most powerful data base from which to draw information about pollutant strength, distribution, transport processes, and species interaction. Characterization of air masses such as the event encountered on July 9 demonstrates the degree of completeness and the amount of detailed information available for investigation of tropospheric transport and chemical synergism.

Comparative evaluation of data from July 9 and 15 suggests that the relationship between CO and O_3 within the mixed layer is dependent on concentration-related phenomena. The slopes of the concentration gradients for CO and O_3 observed in the highly polluted haze layer were directly correlated. Conversely, the CO and O_3 concentrations observed in the more pristine Caribbean region were generally anticorrelated.

Extensive use of real time information provided by the lidar system enhances our ability to obtain a complete three-dimensional picture of the atmosphere. Real time data analysis also has the potential for increasing the cost effectiveness of aircraft utilization due to the ability to make *in situ* sampling decision.

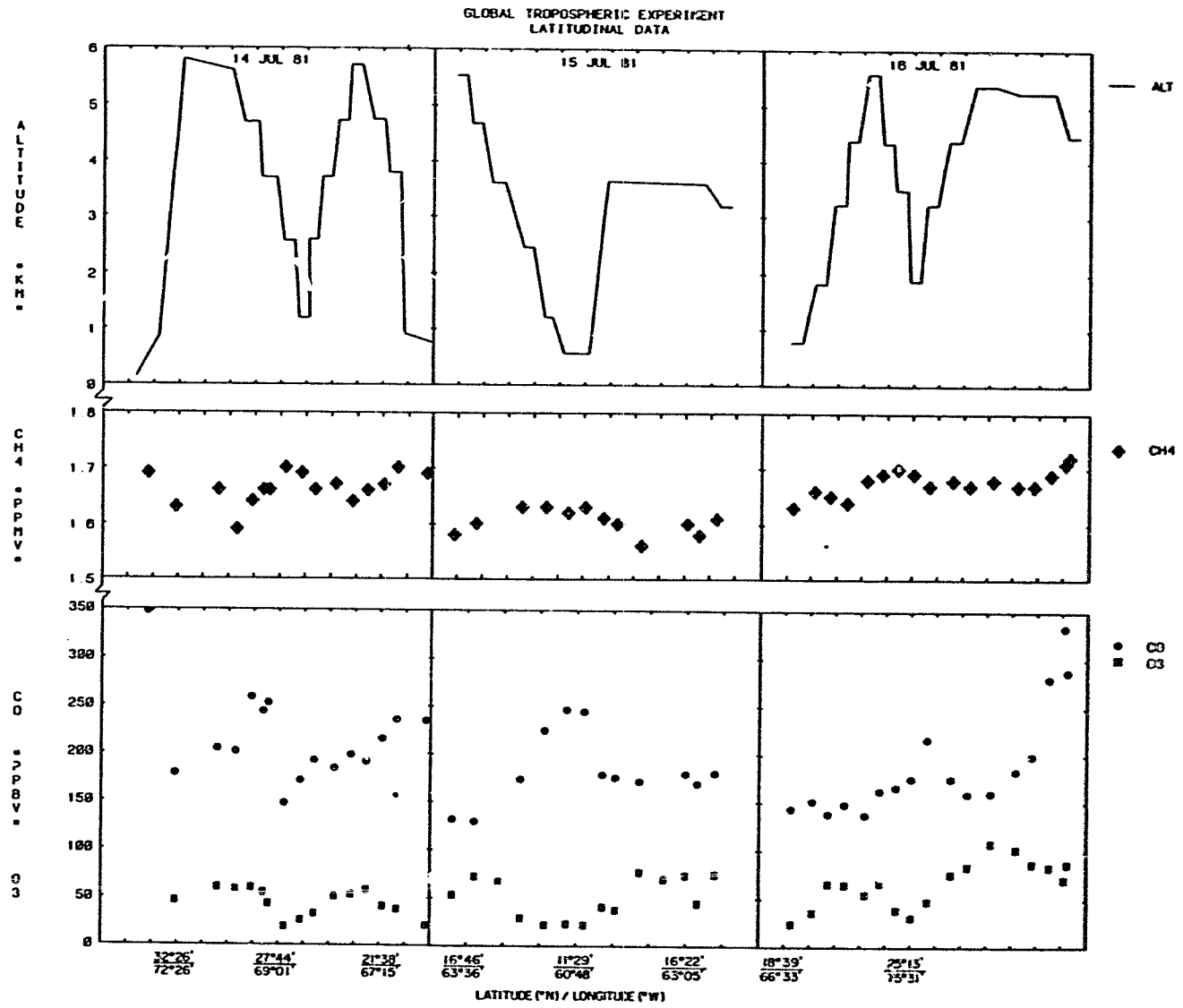

Figure 6. Ozone, carbon monoxide, and methane concentrations with respect to altitudes flown over the latitudinal range of the Global Tropospheric Experiments test flights.

LITERATURE CITED

Browell, E.V. and S.T. Shipley (in press): Airborne Lidar Investigations of Aerosol and Ozone in the Nonurban Troposphere. Second Symposium on Composition of the Nonurban Troposphere. Williamsburg, VA, May 25-29, 1982.

Condon, E.P. 1977. A Measurement System for the Atmospheric Trace Gases CH_4 and CO. Tech. Rep. PGSTR-AP77-61. Old Dominion University Research Foundation. Norfolk, VA.

Seiler, W. and J. Fishman. 1981. The Distribution of Carbon Monoxide and Ozone in the Free Troposphere. J. Geophys. Res. 86 (C8) 7255-7265.

Swinnerton, J.W. and V.J. Linnebom. 1967. Determination of the C_1 and C_4 Hydrocarbons in Seawater by Gas Chromatography. J. Gas Chromatog. 5:570.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1968. A Sensitive Gas Chromatographic Method for Determining Carbon Monoxide in Seawater. Limnol. Oceanog. 13:193.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1962a. Determination of Dissolved Gases in Aqueous Solutions by Gas Chromatography. Anal. Chem. 34:483.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1962b. Revised Sampling Procedures for Determination of Dissolved Gases in Solution by Gas Chromatography. Anal. Chem. 34:1509.

APPENDIX B

MAPS/OSTA-1 EAST COAST CORRELATIVE MEASUREMENTS CARBON MONOXIDE RESULTS

R. R. Hinton

February 1, 1982

MAPS/OSTA-1 EAST COAST CORRELATIVE MEASUREMENTS
CARBON MONOXIDE RESULTS

INTRODUCTION

This interim document reports the preliminary evaluation of carbon monoxide (CO) grab sample data taken during the MAPS/OSTA-1 east coast Correlative Measurements Program. The program successfully completed a series of underflights to obtain "ground truth" information to support interpretation of shuttle-borne gas filter correlation radiometer (GFCR) data. The program is a part of a continuing effort to monitor CO concentration on a global scale. Old Dominion University Research Foundation has participated in development, testing, and data reduction aspects of the MAPS experiment since the early 1970's. Thus, the OSTA-1 related information reported here represents a milestone of considerable magnitude.

Analytical support was provided for two flights during the 56-hour Shuttle Mission Simulation, two flights for equipment tests, and two flights during the actual STS-2 Columbia orbital mission. The following services were performed:

- maintenance and leak testing of grab sample bottles
- assembly and leak testing of grab sample bottles
- preparation of two aircraft pump pallet assemblies
- distribution of interlaboratory calibration gases
- analysis of samples and standards
- reduction of data
- reporting of results
- assistance in interpretation of results

SAMPLING AND ANALYTICAL METHODS

The sampling platform was a Lear Jet Model (Figure 1) modified with grab sampling and instrument/camera viewing ports. Data was collected under simulated or actual shuttle flight tracks during passage overhead. During the MAPS/OSTA-1 mission, grab samples were collected near Farmville, VA under Orbit 18 and near Key West, FL under Orbit 21 (Figure 2). Two samples were also taken near Orbit 20. The nominal sampling flight path was a "bow

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Figure 1. The Lear Jet Model 25, the sampling platform for the correlative measurements program.

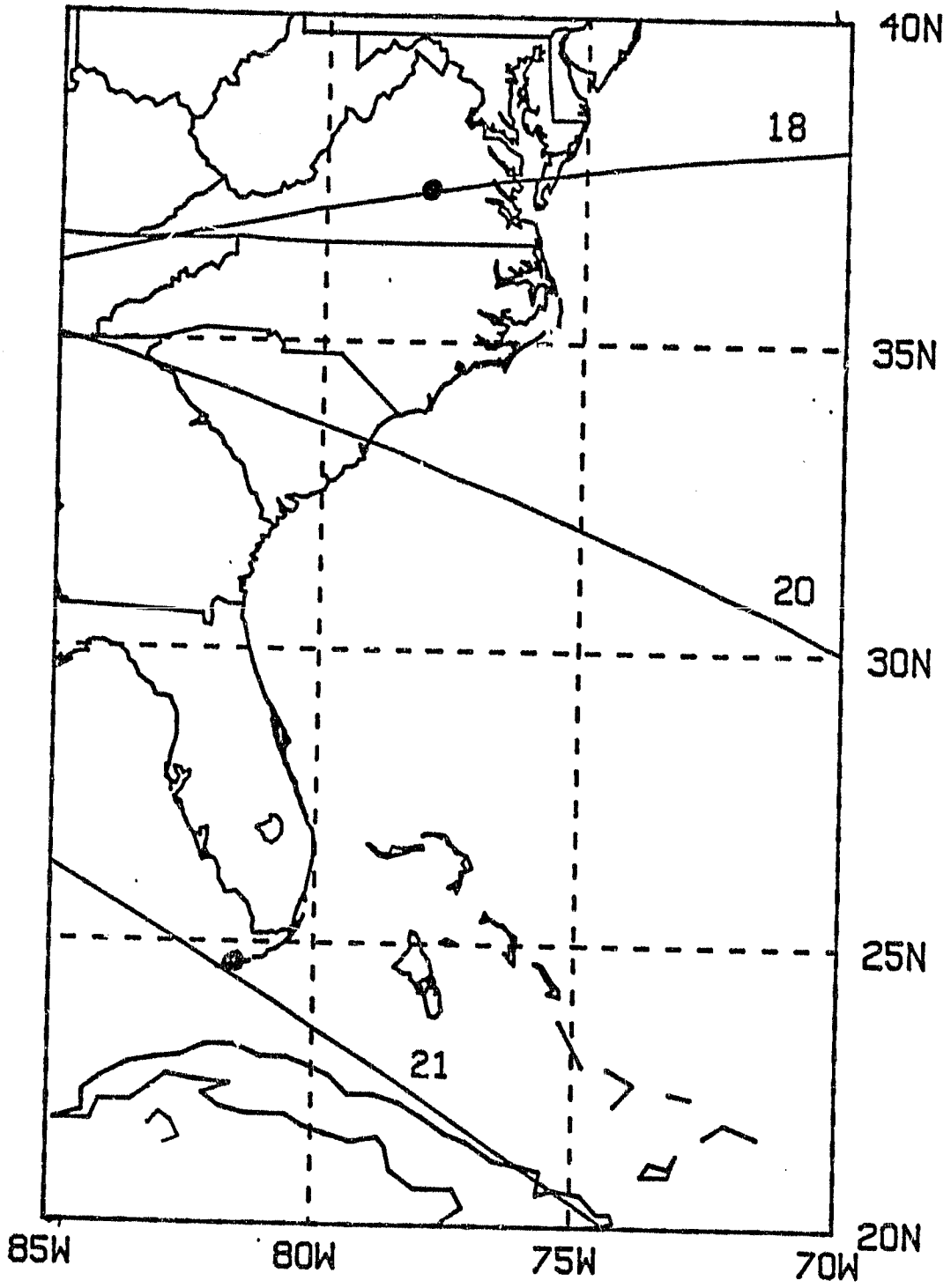

Figure 2. Location of correlative sampling with respect to orbital flight paths.

tie" pattern flown at 41,000 ft. (12.5 km) ASL with a vertical spiral flown at the "knot" in the center (Fig. 3). Radiometer data was collected continuously during descent and grab samples were taken at 4,000 ft (1.2 km) intervals.

Grab samples were collected in 300 ml stainless steel bottles. Bottles were preconditioned by heating in air to 1000°C to remove contaminants (e.g., tooling lubricants, fingerprints, solvents). Following preconditioning, bottles were assembled in racks of ten (wt. 11.4 kg) to facilitate handling and securing of sample containers in an aircraft. Space constraints in the cabin of the Lear Jet limited the number of sample bottles carried of twenty. Bottle racks were secured by locking pins to the forward section of a pallet installed in an aircraft equipment rack. The rear section of the pallet held two 1/8 HP neoprene diaphram pumsp connected in series by stainless steel tubing (Figure 4). Outside air was drawn through a pitot-like stainless steel inlet port located abeam the aircraft cabin door. The inlet port was valved to prevent entraining debris into the pumps during takeoffs and landings.

Prior to each sample collection, the pumps were operated for at least one minute to purge the system with ambient air. During the spiral descent, the pumps operated continuously. Each previously evacuated sample bottle was filled and flushed twice before the final filling to a pressure of 28 to 30 psig.

Samples were returned to the laboratory and analyzed by flame ionization (FID) gas chromatography (Figure 5). A modified analytical technique (Condon, 1977) similar to that of Swinnerton, et al. (1962, 1962a, 1967, 1968) was used to measure CO in trace amounts. The pressurized sample bottle is connected to a gas transfer manifold. The grab sample flushes and fills a 100 ml sample loop. The sample is carried by transfer helium (He) through two liquid nitrogen cold traps. The first trap of activated alumina with 10 percent by weight paraffin oil removes CO_2 and hydrocarbons heavier than methane (CH_4). A drying tube of magnesium perchlorate removes water. The second cold trap of 25 percent by weight activated charcoal and 75 percent molecular sieve 5A 60/80 mesh removes CO and CH_4. The traps are isolated by valves, allowed to warm to room temperature, and raised to 100°C with boiling water to desorb the CO and CH_4. The carrier He (flown rate

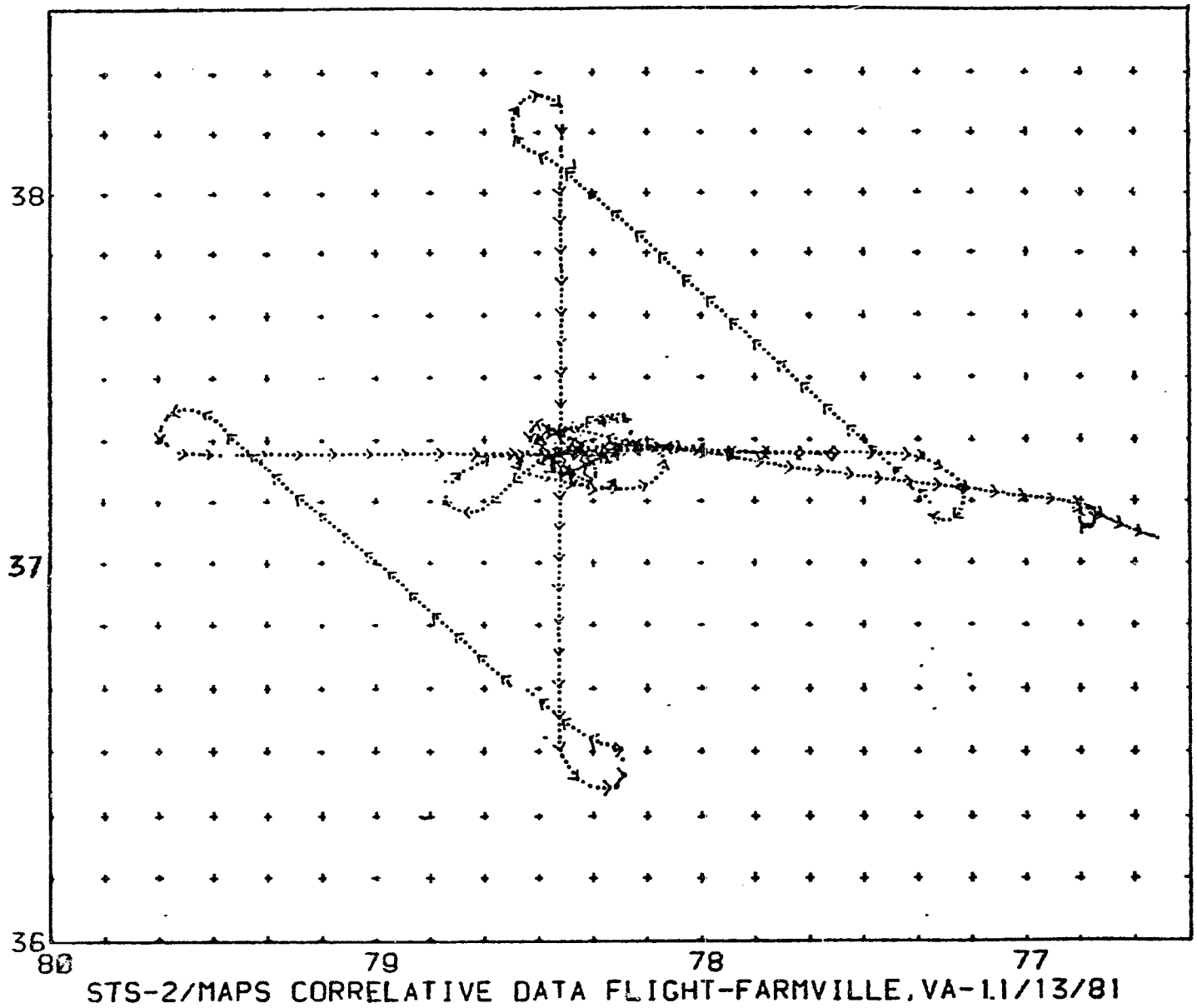

Figure 3. The nominal "bow-tie" sampling flight path as flown during underflight for STS-2 Columbia Orbit 18 over Farmville, VA, November 13, 1981.

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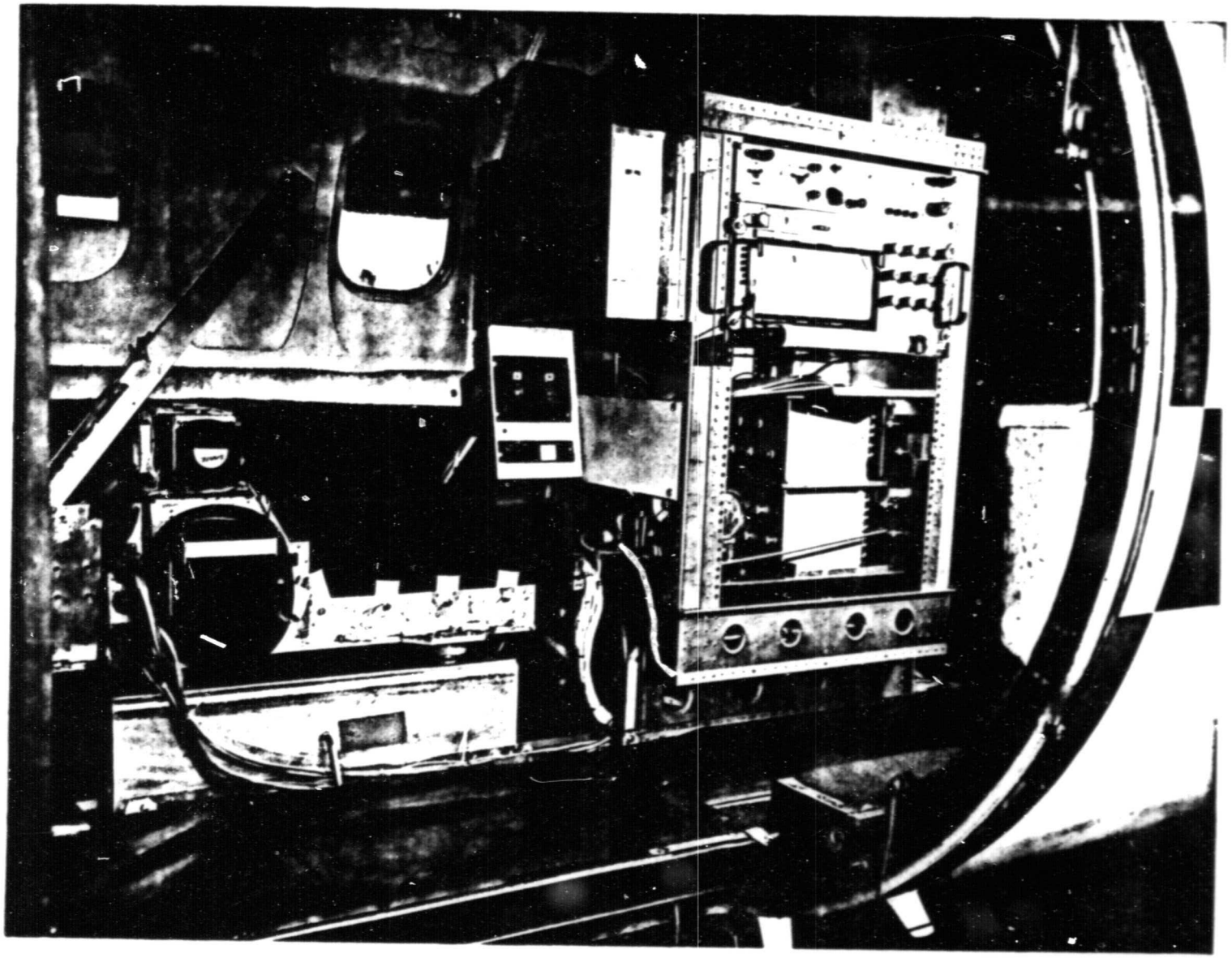

Figure 4. The grab sampling pallet with pumps connected in series and two racks of sample bottles installed in the aircraft.

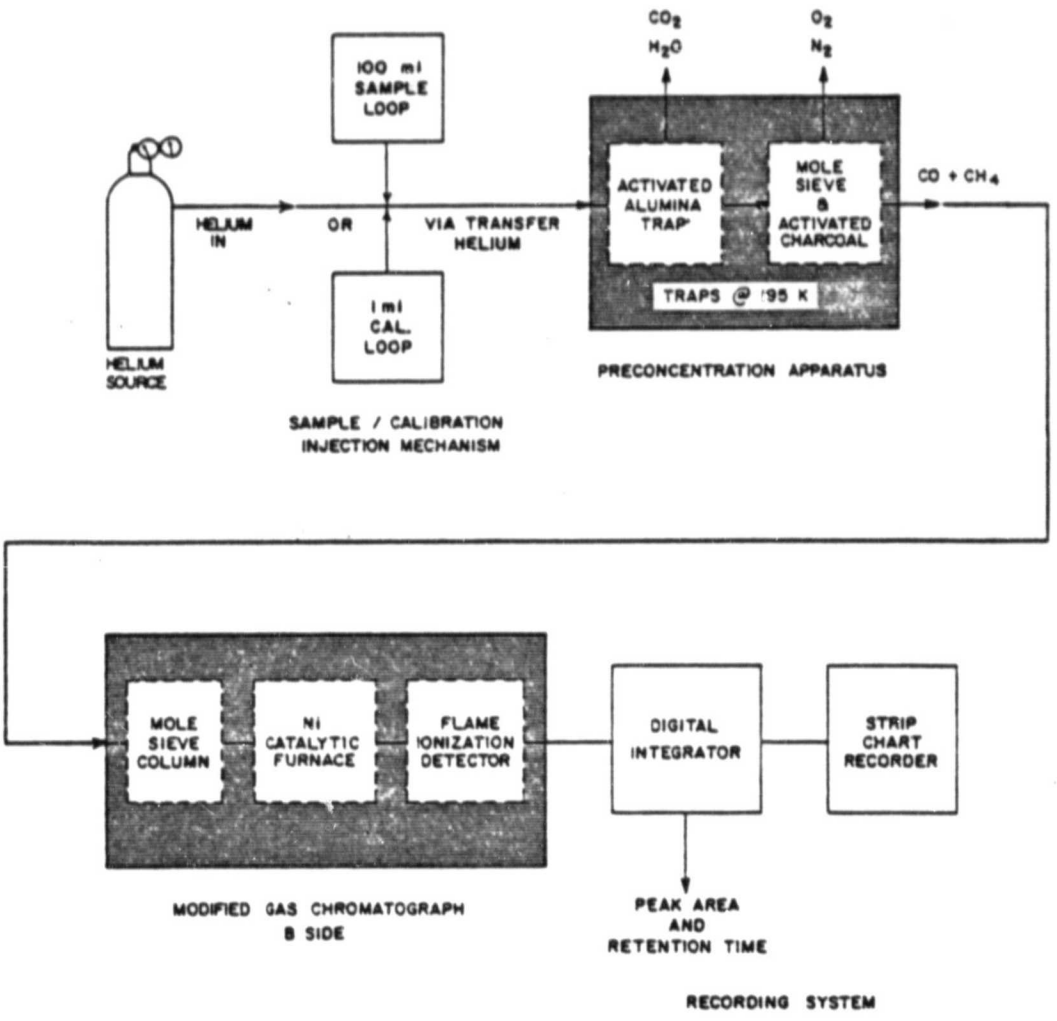

Figure 5. Flow diagram of the laboratory gas analysis system.

60 ml/min.) moves the sample through a 2 m length of 0.6 cm column packed with molecular sieve 5A and held at ~100°C. Because CO is not directly detectable using FID, the CO is catalytically reduced over hot (325°C) nickle and detected as the second CH_4 peak to elute. The sample CH_4 elute about one min. earlier (Figure 6). Peak areas are reported as counts by a digital integrator and plotted on a strip chart. Sample concentrations are read from a calibration plot. Calibration plots are made by plotting the peak areas of various calibration gas standards with known concentration gas with an appropriate concentration of CO and CH_4, is analyzed every third or fourth sample to correct for instrument drift all samples were analyzed within 36 hrs of being taken.

RESULTS

Data from the Correlative Measurements Program are summarized in Tables 1 and 2 for the OSTA-1 Orbits 18 and 21, respectively. The last sample listed in Table 1 was not included in the data analysis because it was taken outside the spiral sampling flight path. Figures 7 and 8 show the data in graphic form. Polynomial regression curves were fit to the carbon monoxide grab sample data and the R-square values indicating goodness of fit are given in Table 3. Because such a large percentage of the residuals was attributed to the sample at 29,300 ft, curve fitting was done with and without this data point. Such a dramatic increase in CO concentration at altitude may have resulted from a "shearing" effect caused by the air masses of different trajectories crossing at higher altitudes. (There is some evidence from a meteorological model to support this hypothesis.) It is also possible that there was an error in the analysis of the sample taken at 29,300 ft; however, inspection of samples and standards run about the same time give no indication of an analytical error. There is also a possibility that the bottle leaked and, instead of a vacuum, actually contained surface air. Such contamination could result in a higher value.

The CO concentration for all samples taken under Orbit 18 averaged 89.8 ± 42.2 ppbv mixing ratio. The average for Orbit 21 was 87.0 ± 47.3 ppbv mixing ratio. During the entire analysis an internal standard gas was analyzed to measure instrument drift. Drift during analysis of samples from Orbit 18 was less than 3%. Drift during analysis of Orbit 21 samples was

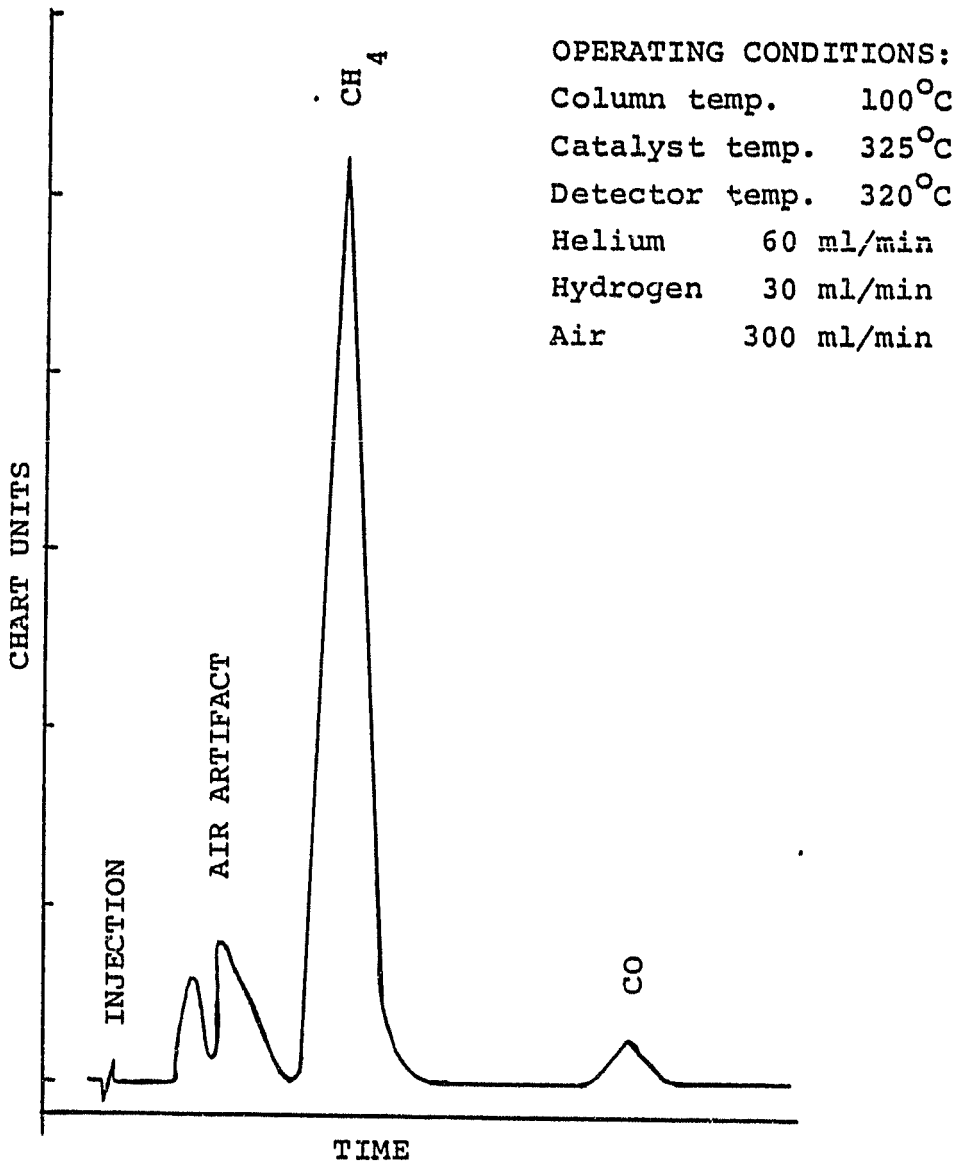

Figure 6. A typical sample chromatogram.

Table 1. MAPS/OSTA-1 Lear jet correlative measurements--Orbit 18, Farmville, VA, November 13, 1981.

Altitude									Tot. T				
A/C ALT (ft)	DPH ALT (ft)[1]	ALT (km)	Pressure (mb)[2]	Latitude (°N)	Longitude (°W)	Time (GMT)	MACH No.	DP (°C)[3]	(V)	(°C)[4]	SATM (°C)[5]	Bottle No.	CO (ppbv)
41,500	41,900	12.65	174.5	37°17.7	73°22.1	15:35:53	0.7	ND	2.36	-40.0	-60.8	10	44
41,600	42,000	12.68	173.6	37°17.5	77°21.9	15:42 55	0.7	ND	2.45	-38.2	-59.2	11	43
41,600	42,000	12.68	173.6	38°00.4	78°23.2	15:57:14	0.7	ND	2.34	-40.3	-61.1	12	46
41,600	42,200	12.68	173.6	36°36.7	78°25.9	16:16:18	0.72	-49.2	2.56	-37.1	-59.2	13	49
41,500	42,100	12.65	174.5	37°15.7	79°20.6	16:31:14	0.7	-49.0	2.51	-37.6	-58.7	14	50
41,700	42,100	12.71	172.8	37°17.6	78°32.1	16:42:23	0.72	-48.8	2.56	-36.6	-58.8	15	44
37,400	37,800	11.40	212.5	37°22.5	78°25.1	16:46:17	0.68	-49.2	2.53	-38.5	-58.4	16	70
33,300	33,800	10.15	258.4	37°13.1	78°25.0	16:49:05	0.68	-49.2	2.93	-31.5	-52.0	17	87
33,300	33,800	10.15	258.4	37°12.0	78°15.5	16:50:18	0.66	-48.6	2.82	-33.7	-52.9	18	94
29,300	29,800	8.93	310.6	37°19.7	78°14.2	16:52:45	0.64	-47.5	3.40	-23.6	-42.5	19	139
25,400	26,000	7.74	369.5	37°15.1	78°23.8	16:55:51	0.57	-44.9	3.84	-17.1	-32.8	50	94
21,400	21,900	6.52	439.0	37°18.0	78°18.8	16:58:36	0.50	-41.8	4.28	-11.1	-23.6	51	75
21,400	21,800	6.52	439.0	37°41.2	78°25.7	16:59:53	0.5	-40.6	4.28	-11.4	-23.9	52	75
16,400	17,200	5.00	540.3	37°15.8	78°25.8	17:02:20	0.35	-38.1	4.82	-3.1	-9.5	53	98
13,000	13,300	3.96	619.4	37°19.2	78°24.4	17:04:56	0.35	-23.2	5.29	+3.4	-3.2	54	124
9,100	9,600	2.77	721.5	37°17.9	78°25.4	17:07:20	0.34	-21.7	5.72	10.4	4.0	55	108
9,000	9,300	2.74	724.3	37°17.5	78°20.7	17:08:20	0.34	-21.1	4.68	10.1	3.7	56	118
4,900	5,300	1.49	846.2	37°18.2	78°23.8	17:11:03	0.34	-26.6	5.85	12.5	6.0	57	159
800	1,100	0.24	984.3	37°15.8	78°21.7	17:13:40	0.33	-12.9	5.87	13.0	6.9	58	190
14,500[6]	15,200	4.42	--	37°19.0	78°08	17:16:23	(0.35)	-24.81	5.26	3.5	-3.5	59	213

[1]Altimeter reading taken from dew point hygrometer port. Used as back-up altimeter.
[2]Pressure in millibars from Standard Atmosphere 1976 corrected for aircraft altimeter setting.
[3]Original data in volts. T_{DP} 20*V - 50; then converted to dew point by interpolating Smithsonian tables of saturation vapor pressure over ice and water.
[4]Outside air temperature (TOT. T) = 15*V - 75.
[5]Standard air temperature corrected for MACH number (SATM) = $\frac{\text{TOT. T} + 273.15}{1 + 0.2\ (\text{MACH})^2} - 273.15$.
[6]Sample taken outside of spiral and not considered as part of nominal sampling pattern
ND = No data.

Table 2. MAPS/OSTA-1 Lear jet correlative measurements--Orbit 21, Key West, FL, November 13, 1981.

Altitude									Tot. T				
A/C ALT (ft)	DPH ALT (ft)[1]	ALT (km)	Pressure (mb)[2]	Latitude (°N)	Longitude (°W)	Time (GMT)	MACH No.	DP (°C)[3]	(V)	(°C)[4]	SATM (°C)[5]	Bottle No.	CO (ppbv)
41,300	41,900	12.58	179.3	33°32.8	79°25.2	19:45:01	0.72	ND	2.65	-36.0	-58.3	20	58
41,300	41,900	12.58	179.3	33°21.4	79°38.5	19:47:33	0.7	ND	2.54	-37.4	-58.4	21	57
41,200	41,900	12.56	180.2	26°08.8	81°46.6	20:59:55	0.7	ND	2.50	-37.8	-58.8	22	57
41,200	41,900	12.56	180.2	25°32.9	81°46.8	21:05:44	0.7	ND	2.47	-38.5	-59.5	23	55
41,300	41,900	12.58	179.3	24°57.2	81°47.5	21:11:22	0.7	ND	2.40	-39.3	-60.1	24	53
41,300	41,900	12.58	179.3	24°39.0	81°47.7	21:14:16	0.7	ND	2.42	-38.7	-59.6	25	46
41,100	41,500	12.53	181.1	24°28.9	81°47.6	21:15:54	0.7	ND	2.42	-39.8	-60.7	26	44
37,300	37,900	11.37	217.9	24°36.7	81°32.8	21:22:17	0.7	ND	3.06	-29.7	-51.5	27	48
33,200	33,800	10.12	264.1	24°45.9	81°30.9	21:25:28	0.68	-47.7	3.76	-20.4	-41.8	28	52
33,200	33,800	10.12	264.1	24°45.9	81°41.7	21:27:20	0.68	-46.1	3.72	-19.9	-41.4	29	55
29,300	29,900	8.93	315.2	24°57.5	81°42.3	21:29:57	0.63	-43.9	4.18	-12.6	-32.3	80	74
25,200	25,900	7.68	377.6	25°03.2	81°42.7	21:33:15	0.64	-34.4	4.73	-4.7	-24.4	81	74
21,300	22,000	6.49	446.3	24°46.6	81°45.2	21:36:08	0.54	-30.7	4.93	-1.5	-16.4	82	76
21,200	21,800	6.46	448.2	24°41.3	81°47.0	21:37:17	0.51	-36.5	4.91	-1.8	-15.2	83	75
17,200	17,900	5.24	529.3	24°41.3	81°51.1	21:39:39	0.35	-31.4	5.35	4.5	-2.1	84	108
13,200	13,700	4.02	622.0	24°30.5	81°52.7	21:42:14	0.35	-31.2	5.68	10.3	3.5	85	110
9,300	9,700	2.83	724.6	24°31.2	81°54.4	21:45:01	0.34	5.7	5.97	14.4	7.9	86	154
9,200	9,600	2.80	724.4	24°34.6	81°58.4	21:45:54	0.34	5.3	5.92	13.3	6.9	87	145
5,200	5,600	1.58	846.4	24°32.2	81°57.0	21:48:44	0.34	9.2	6.24	18.3	11.7	88	123
1,200	1,600	0.37	980.2	24°34.9	81°48.8	21:50:56	0.32	14.3	6.75	26.1	20.1	89	217

[1]Altimeter reading taken from dew point hygrometer port. Used as back-up altimeter.
[2]Pressure in millibars from Standard Atmosphere 1976 corrected for aircraft altimeter setting.
[3]Original data in volts. T_{DP} 20*V - 50; then converted to dew point by interpolating Smithsonian tables of saturation vapor pressure over ice and water.
[4]Outside air temperature (TOT. T) = 15*V - 75.
[5]Standard air temperature corrected for MACH number (SATM) = $\frac{\text{TOT. T} + 273.15}{1 + 0.2\ (\text{MACH})^2} - 273.15$.
[6]Samples taken in the vicinity of Orbit 20 enroute to Key West, FL.

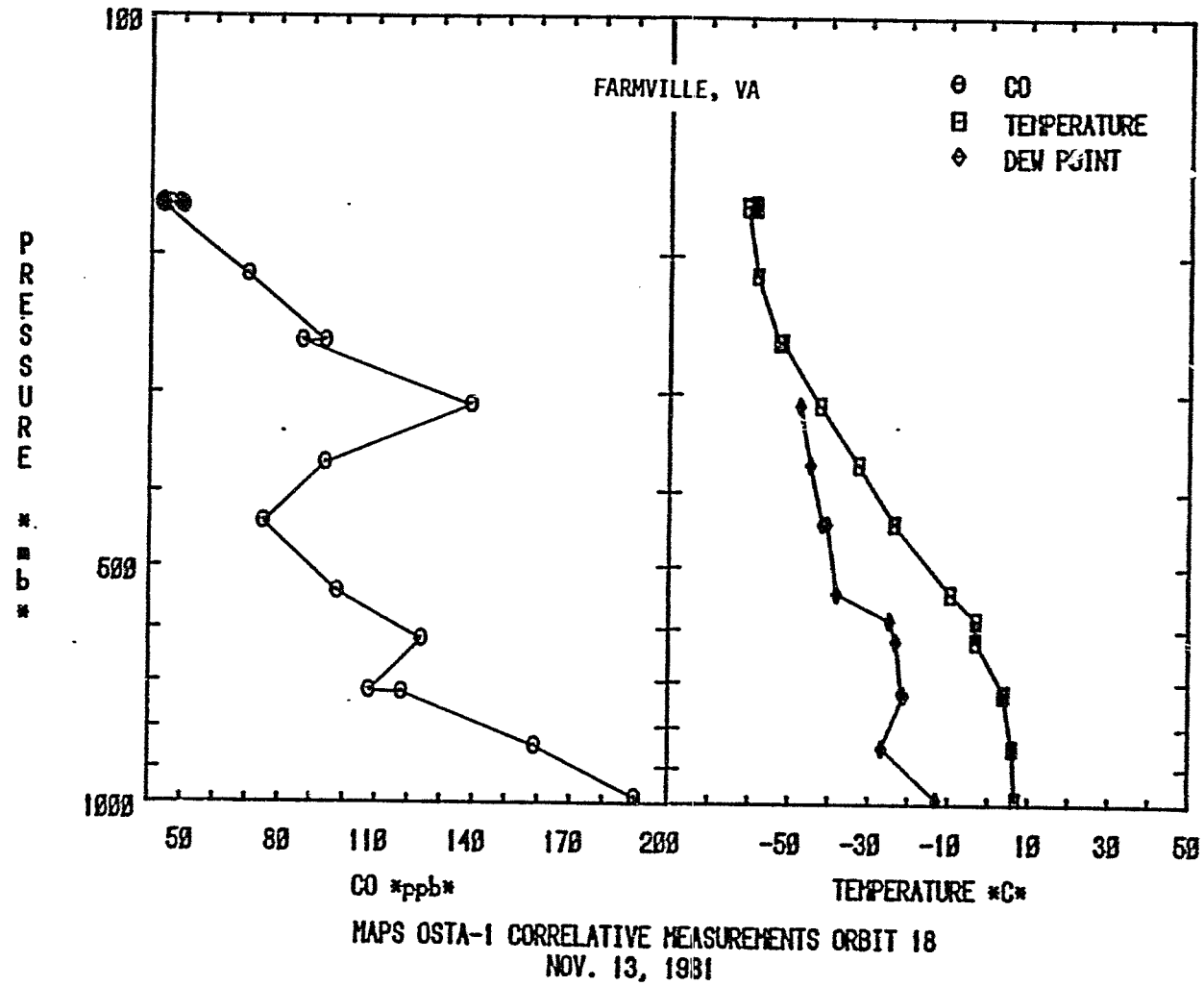

Figure 7. MAPS/OSTA-1 correlative measurements Orbit 18, November 13, 1981, Farmville, VA.

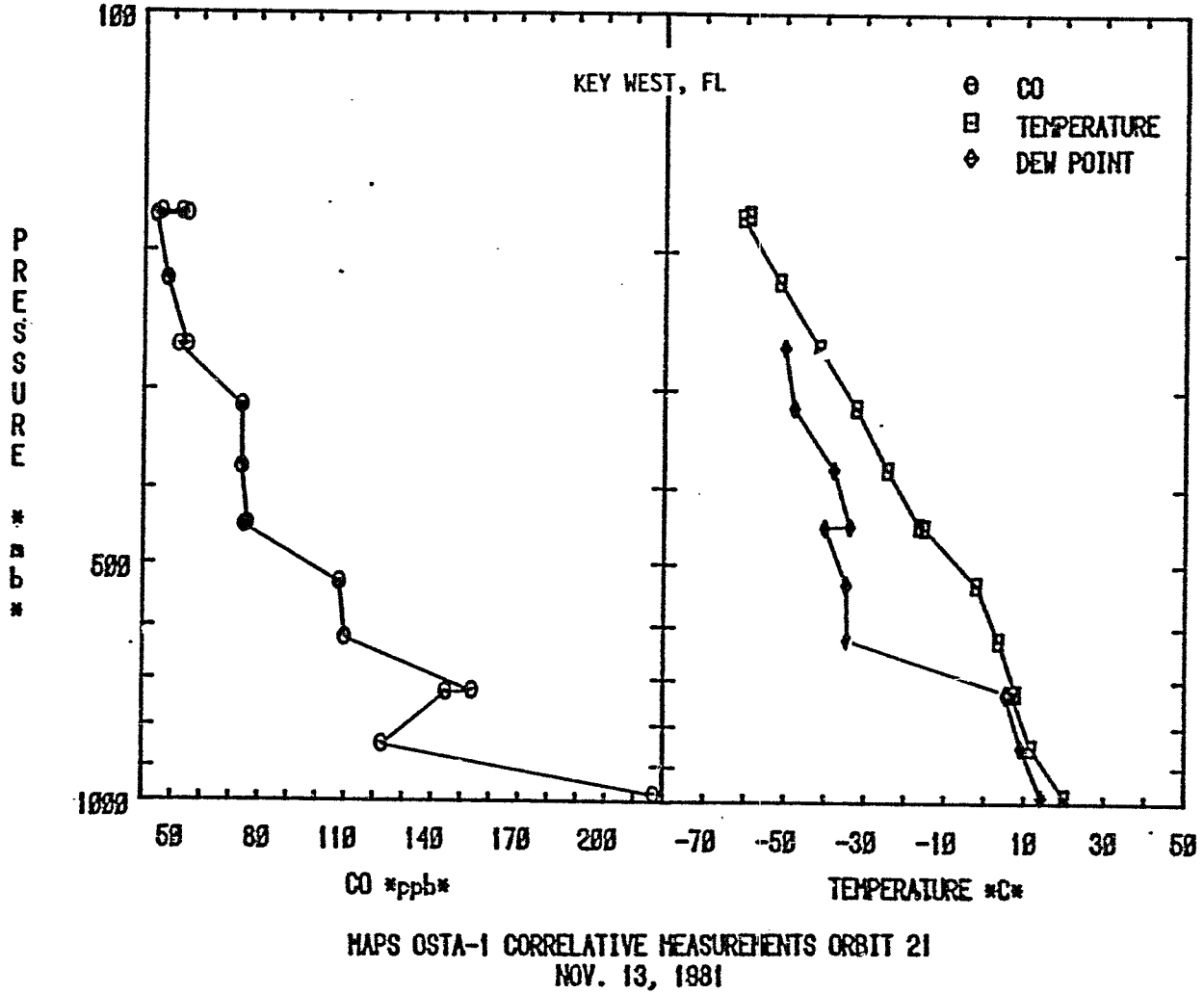

Figure 8. MAPS/OSTA-1 correlative measurements Orbit 21, November 13, 1981, Key West, FL.

Table 3. R-square values for various curves fit to carbon monoxide data from MAPS/OSTA-1 correlative measurements.

	Using All Data Points	Omitting Sample at 29,300 ft
Orbit 18--Farmville, VA, November 13, 1981		
First-Order Polynomial	0.748	0.831
Second-Order Polynomial	0.762	0.863
Third-Order Polynomial	0.769	0.867
Orbit 21--Key West, FL, November 13, 1981		
First-Order Polynomial	0.819	
Second-Order Polynomial	0.923	
Third-Order Polynomial	0.959	

less than 3%. Both values are within acceptable performance levels for gas chromatography. Some samples for Orbit 21 were collected in clouds and the wetness of the samples may have contributed to the increased drift.

Data from the 56-hour Shuttle Simulation are summarized in Tables 4 and 5. The mean CO concentration for Orbit 20 was 233.8 ± 23.8 ppbv mixing ratio and for Orbit 51 was 243.6 ± 20.7 ppbv mixing ratio.

Obviously, there are large seasonal/meteorological differences in CO values obtained during the 56-hour Simulation in early September and CO values from the actual Shuttle mission in mid-November.

TASKS TO BE COMPLETED

The purpose of this preliminary report was to organize the CO and physical data to take a "quick look" approach to the data analysis, and to serve as initial action toward a final report. The following are the major tasks remaining:

- interpretation of results;
- organization of data from other correlative flights;
- processing of interlaboratory calibration data;
- examination of CO data with respect to relevant meteorological information;
- recommendations for improvements in future correlative measurements program.

Table 4. 56-hour shuttle simulation--Orbit 20, September 2, 1981.

Altitude								Tot. T					
A/C ALT (ft)	DPH ALT (ft)[1]	ALT (km)	Latitude (°N)	Longitude (°W)	Time (GMT)	MACH No.	DP (°C)	(V)	(°C)[2]	SATM (°C)[3]	Bottle No.	CH_4 (ppmv)	CO (ppbv)
41,200	42,000	12.56	33°17	78°32	15:33	0.7	ND	2.61	-35.9	-57.1	10	1.62	245
41,000	42,000	12.50	33°17	71°49	15:38	0.7	ND	2.65	-35.3	-56.5	11	1.59	199
41,300	42,000	12.59	34°02	78°44	15:51	0.7	-47	2.65	-35.3	-56.5	12	1.60	232
41,200	42,000	12.56	32°30	78°44	16:06	0.7	-46	2.56	-36.6	-57.7	13	1.58	198
41,300	42,000	12.59	33°16	74°37	16:19	0.7	-46	2.51	-37.4	-58.4	14	1.60	235
41,200	41,900	12.56	33°16	78°44	16:29	0.7	-46	2.54	-36.9	-58.0	15	1.64	240
36,900	38,700	11.25	33°25	78°36	16:32	0.68	-45	3.00	-30.0	-50.5	16	1.71	254
33,100	34,900	10.15	33°14	78°34	16:34	0.68	-42	3.55	-21.8	-42.9	17	1.64	248
29,100	34,900	10.09	33°19	78°21	16:36	0.66	-41	3.53	-22.1	-42.2	18	1.64	233
25,200	30,100	8.87	33°20	78°47	16:39	0.64	-35	4.12	-13.2	-32.9	19	1.62	233
21,200	25,700	7.68	33°13	78°42	16:41	0.57	-32	4.53	-7.1	-23.3	80	1.57	211
21,100	21,700	6.46	33°23	78°38	16:44	0.5	-28	5.02	-0.3	-12.7	81	1.57	209
17,200	21,600	6.43	33°22	78°44	16:45	0.5	-26	4.96	-0.6	-13.6	82	1.59	210
13,000	17,900	5.24	33°17	78°44	16:48	0.35	-21	5.62	-9.3	-2.4	83	1.59	205
9,000	13,400	3.96	33°21	78°51	16:50	0.35	-13	5.72	-10.8	- 3.9	84	1.60	240
9,000	9,400	2.74	33°17	78°47	16:53	0.34	+1	6.21	-18.2	-11.6	85	1.60	239
5,000	9,400	2.74	33°17	78°45	16:54	0.34	+1	6.10	-16.5	-10.0	86	1.62	260
1,500	5,300	1.52	33°21	78°40	16:56	0.34	+5	6.57	-23.6	-16.9	87	1.60	283
1,000	1,400	0.30	33°20	78°44	16:59	0.32	+12	6.91	-28.7	-22.3	88	1.66	271
2,600[4]	2,900	0.79	32°48	74°54	17:13	0.33	+16	ND	ND	ND	89	1.64	299

[1]Altimeter reading taken from Dew Point Hygrometer Port. Used as back-up altimeter.
[2]Outside air temperature (TOT. T) = 15 V - 75.
[3]Standard air temperature corrected for MACH number (SATM) = $\frac{\text{TOT. T} + 273.15}{1 + 0.2\ (\text{MACH})^2} - 273.15$.
[4]Sample taken outside of spiral and not considered as part of nominal sampling pattern.
ND = No data.

Table 5. 56-hour shuttle simulation--Orbit 20, September 3, 1981, Denton, NC.

Altitude								Tot. T					
A/C ALT (ft)	DPH ALT (ft)[1]	ALT (km)	Latitude (°N)	Longitude (°W)	Time (GMT)	MACH No.	DP (°C)	(V)	(°C)[2]	SATM (°C)[3]	Bottle No.	CH_4 (ppmv)	CO (ppbv)
41,200	42,100	12.56	35°49	76°32	13:19	0.7	ND	2.59	-36.2	-57.3	20	1.59	225
41,000	42,000	12.53	35°49	75°49	13:22	0.7	ND	2.53	-37.1	-58.2	21	1.59	218
41,200	42,900	12.56	35°33	76°44	13:35	0.7	ND	2.47	-38.0	-59.0	22	1.59	227
41,300	42,100	12.59	35°06	76°44	13:50	0.7	ND	2.54	-36.9	-57.9	23	1.57	216
41,200	42,800	12.56	35°51	71°37	14:04	0.7	-44	2.58	-36.3	-57.4	24	1.58	223
41,200	42,600	12.56	35°50	76°44	14:12	0.7	-45	2.40	-39.0	-59.9	25	1.59	219
37,000	39,000	11.28	35°51	76°36	14:14	0.68	-45	2.99	-30.2	-50.7	26	1.62	250
33,200	35,300	10.12	35°50	76°34	14:17	0.68	-43	3.67	-19.9	-41.2	27	1.61	254
33,000	35,300	10.06	35°46	76°21	14:18	0.66	-41	3.74	-18.9	-39.2	28	1.61	252
29,100	30,400	8.84	35°46	76°47	14:23	0.64	-35	4.26	-11.1	-31.0	29	1.59	222
25,100	26,300	8.02	35°47	76°42	14:24	0.57	-29	4.85	-2.3	-18.8	35	1.59	278
21,100	21,900	6.43	35°44	76°38	14:29	0.5	-24	5.17	-2.6	-10.5	36	1.61	226
21,000	21,600	6.40	35°45	76°44	14:30	0.5	-24	5.02	-0.3	-12.7	37	1.61	235
17,000	17,400	5.18	35°47	76°44	14:33	0.35	-9	5.50	-7.5	-0.7	38	1.59	246
13,000	13,500	3.96	35°46	76°51	14:36	0.35	-2	6.02	+15.3	-8.3	39	1.59	249
9,000	9,600	2.74	35°51	76°47	14:39	0.34	+3	6.29	+19.4	-12.8	34	1.62	267
9,000	9,600	2.74	35°53	76°45	14:40	0.35	+3	6.31	+19.7	-13.1	33	1.64	276
15,000	15,900	4.57	35°11	76°40	14:43	0.35	-5	5.84	+12.6	-5.6	32	1.61	259
15,000	16,000	4.57	36°16	76°44	14:45	0.35	-5	5.86	+12.9	5.9	31	1.59	270
13,800[4]	14,700	4.21	36°21	76°54	14:46	0.34	-3	5.99	+14.9	8.4	30	1.58	260

[1]Altimeter reading taken from Dew Point Hygrometer Port. Used as back-up altimeter.
[2]Outside air temperature (TOT. T) = 15 V - 75.
[3]Standard air temperature corrected for MACH number (SATM) = $\frac{\text{TOT. T} + 273.15}{1 + 0.2\ (\text{MACH})^2} - 273.15$.
[4]Sample taken outside of spiral and not considered as part of nominal sampling pattern.
ND = No data.

LITERATURE CITED

Condon, E.P. 1977. A Measurement System for the Atmospheric Trace Gases CH_4 and CO. Tech. Rep. PGSTR-AP77-61. Old Dominion University Research Foundation. Norfolk, VA.

List, Robert J. (Ed) Smithsonian Meteorological Tables. Sixth Edition. Smithsonian Institution Press. Washington, DC 502 pp.

Swinnerton, J.W. and V.J. Linnebom. 1967. Determination of the C_1 to C_4 Hydrocarbons in Seawater by Gas Chromatography. J. Gas Chromatog. 5:570.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1968. A Sensitive Gas Chromatographic Method for Determining Carbon Monoxide in Seawater. Limnol. Oceanog. 13:193.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1962a. Determination of Dissolved Gases in Aqueous Solutions by Gas Chromatography. Anal. Chem. 34:483.

Swinnerton, J.W., V.J. Linnebom, and C.H. Cheek. 1962b. Revised Sampling Procedures for Determination of Dissolved Gases in Solution by Gas Chromatography. Anal. Chem. 34:1509.